

Impact of Heavy Metals on Haematological Parameters of Fishes: A Review

Chiranjeev Pandey* & Alka Mishra

Department of Zoology, Government V.Y.T. Autonomous Postgraduate College, Durg (C.G.) India

Abstract: Heavy metal contamination poses a serious ecological threat to aquatic ecosystems, affecting fish physiology, haematology, and survival. This review synthesizes current research on the haematological alterations induced by common heavy metals such as cadmium (Cd), lead (Pb), chromium (Cr), copper (Cu), zinc (Zn), and mercury (Hg) in various freshwater and marine fish species. The analysis highlights that exposure to sublethal concentrations of these metals significantly reduces red blood cell (RBC) count, hemoglobin (Hb) concentration, and hematocrit (Hct), while increasing white blood cell (WBC) levels—indicating anemia, hypoxia, and immune stress. Morphological deformations in erythrocytes, including poikilocytosis and anisocytosis, further confirm cellular damage and oxidative stress. Studies across species such as *Oreochromis niloticus*, *Channa punctatus*, *Catla catla*, and *Clarias gariepinus* demonstrate that haematological indices serve as reliable biomarkers of metal-induced toxicity and environmental degradation. Moreover, bioaccumulation in vital organs such as gills, liver, and kidneys reflects the persistence and trophic transfer of metals within aquatic food webs. While considerable progress has been made, knowledge gaps remain regarding chronic exposure, synergistic effects of multiple metals, and molecular mechanisms underlying haematological disruptions. Future research should integrate haematological, biochemical, and genomic biomarkers to develop a holistic framework for aquatic toxicology and environmental monitoring. Overall, this review underscores that continuous haematological assessment of fish populations provides an efficient and non-lethal approach for evaluating aquatic pollution and safeguarding ecological and human health.

Keywords: Heavy metals, Toxicity, FishHaematology, Bioaccumulation, Pollution, Toxicology.

Date of Submission: 25-10-2025

Date of acceptance: 05-11-2025

I. Introduction:

Aquatic ecosystems are increasingly threatened by heavy metal contamination resulting from rapid industrialization, urban runoff, and agricultural waste (Vo et al., 2022). Among aquatic organisms, fish are highly sensitive to environmental pollutants and serve as effective bioindicators of aquatic ecosystem health (Sahiti et al., 2018). Heavy metals such as cadmium (Cd), lead (Pb), copper (Cu), and zinc (Zn) are of particular concern due to their persistence, bioaccumulation, and toxicity, which can disrupt physiological and haematological functions in fish (Kumar & Ram, 2016). Haematological parameters—including red blood cell (RBC) count, hemoglobin (Hb) concentration, hematocrit (HCT), and white blood cell (WBC) count—are vital indicators of fish health, reflecting stress, anemia, and immune response to toxic exposure (Sathick et al., 2018). Exposure to sublethal concentrations of heavy metals can significantly decrease RBC, Hb, and HCT values, while increasing WBC counts, indicating physiological stress and potential impairment of oxygen transport and immune regulation (Vo et al., 2022; Kumar & Ram, 2016). Moreover, morphological alterations in erythrocytes—such as poikilocytosis and anisocytosis—are common in fish subjected to metal pollution, revealing cytotoxic impacts at the cellular level. These haematological disturbances have been reported across multiple species including *Oreochromis sp.*, *Clarias batrachus*, and *Cyprinus carpio* (Sahiti et al., 2018; Vo et al., 2022). Therefore, evaluating the haematological responses of fish to heavy metal exposure provides critical insight into environmental health and the biological impact of aquatic pollution. Heavy metal contamination represents one of the most persistent and hazardous threats to aquatic ecosystems. The rapid pace of industrialization, mining, and urban development has intensified the release of toxic metals such as cadmium (Cd), lead (Pb), mercury (Hg), zinc (Zn), and copper (Cu) into freshwater and marine environments (Mousa et al., 2025). These elements are non-biodegradable, accumulate in sediments and biota, and pose severe risks to aquatic organisms, especially fish, which are vital components of the food web and significant protein sources for humans (Abdulnabi, 2020).

Fish exposed to heavy metals exhibit physiological, histopathological, and haematological alterations that reflect their adaptive responses to environmental stress. Haematological parameters—such as hemoglobin (Hb), red blood cell (RBC) count, hematocrit (HCT), and white blood cell (WBC) count—serve as reliable biomarkers for evaluating fish health and environmental quality (Pandari Reddy & Sunitha Devi, 2019). Variations in these indices often indicate disturbances in oxygen transport, immune response, and metabolic regulation. For example, sublethal exposure to zinc sulfate in *Channa striatus* led to a marked reduction in Hb, RBC, and HCT levels, accompanied by elevated WBC counts, suggesting anemia and compensatory immune activation (Pandari Reddy & Sunitha Devi, 2019).

Similarly, studies on *Oreochromis niloticus* from Egypt's Lake Maryut revealed that elevated concentrations of Cd, Cr, Ni, and Pb correlated with significant declines in RBC count, Hb, and HCT, alongside increased enzymatic activity of AST and ALT—indicative of hepatic stress (Abdulnabi, 2020). These haematological disruptions are consistent with mechanisms such as impaired erythropoiesis, oxidative damage to cell membranes, and disruption of iron metabolism (Gill & Eppele, 1993, as cited in Abdulnabi, 2020).

Marine studies further demonstrate the universality of these effects. In *Mullus barbatus* collected from Sousa Port, Libya, elevated levels of Pb and Fe were detected in both water and fish tissues, exceeding World Health Organization limits. The exposed fish exhibited increased Hb and HCT levels, but reduced thrombocyte counts—indicating hematopoietic imbalance and physiological stress due to metal bioaccumulation (Mousa et al., 2025). These findings underscore that haematological alterations can serve as early indicators of sublethal toxicity, providing valuable diagnostic tools for ecological monitoring.

II. Review of Literature:

Adakole (2012) investigated the long-term haematological effects of industrial metal-finishing effluent on the African catfish (*Clarias gariepinus*). Fish exposed for eight weeks to sublethal effluent concentrations exhibited significant decreases in hematocrit (Ht), hemoglobin (Hb), and mean corpuscular hemoglobin (MCH), with transient increases in erythrocyte and leukocyte counts. The study linked these haematological alterations to the elevated levels of copper and other metals in the effluent, suggesting impaired oxygen transport and immune stress due to metal toxicity.

Al-Hasawi and Hassanine (2023) assessed heavy metal pollution impacts on *Lethrinus harak* from the Red Sea. Elevated levels of Co, Cd, Pb, Cu, and Zn were found in water, sediment, and fish tissues from polluted sites. The contaminated fish exhibited significant increases in liver enzymes (ALT, AST, ALP, GGT), glucose, and triglycerides, and a reduction in total protein—indicating hepatic dysfunction and metabolic disturbance. Histological liver damage confirmed heavy metal-induced toxicity.

Aly et al. (2023) examined the influence of heavy metal contamination (Fe, Zn, Cu, Cd, and Pb) on the haematological and biochemical profiles of *Oreochromis niloticus* from the Ismailia Canal, Egypt. The results showed a decrease in RBC count, Hb concentration, hematocrit (Hct), and mean corpuscular volume (MCV), while MCH and MCHC increased with higher pollution levels. Elevated biochemical markers, such as glucose and total protein, indicated metabolic stress. The findings identified El-Tal Al-Kapeir City as the most contaminated site.

Gandhewar and Zade (2019) evaluated the impact of copper, lead, and cadmium exposure on the haematology of *Heteropneustes fossilis*. After 30 days of exposure, all metals caused marked reductions in total erythrocyte count (TEC), packed cell volume (PCV), and hemoglobin percentage (Hb%), while total leukocyte count (TLC) significantly increased. Copper was found to be the most toxic among the tested metals, followed by lead and cadmium. The study emphasized that such haematological alterations serve as early biomarkers of metal-induced stress.

Garai et al. (2021) provided a detailed review of the toxicity and bioaccumulation patterns of heavy metals such as Cd, Cr, Cu, Pb, Ni, As, Hg, and Zn in fish. The study summarized the mechanisms of metal-induced oxidative stress, DNA damage, and haematological disturbances. It highlighted that chronic exposure to heavy metals leads to anemia, immunosuppression, and hepatotoxicity in fish, with bioaccumulation occurring primarily in gills, liver, and kidneys.

Gupta and Maurya (2023) examined the haematological effects of copper (Cu) and zinc (Zn) contamination in *Channa punctatus* collected from the Gomti River, Lucknow. Their findings revealed that elevated Cu and Zn levels significantly altered several blood parameters, including reductions in hemoglobin (Hb), hematocrit (Hct), and red blood cell (RBC) counts, indicating anemia and physiological stress in fish inhabiting polluted waters. The study highlighted Cu as the dominant contaminant and emphasized haematological biomarkers as sensitive indicators of aquatic heavy metal pollution.

Hamad et al. (2024) studied heavy metal bioaccumulation (Zn, Pb, Cd, Cu) in *Mugil cephalus* from Lake Qaroun, Egypt, and its effects on haematological and histopathological biomarkers. Fish collected from polluted eastern and southeastern sites exhibited significant declines in RBC count, Hb, and Hct compared to those from cleaner western sectors. Histopathological analyses revealed gill lamellae hyperplasia, liver necrosis,

and kidney degeneration. These effects were attributed to chronic exposure to untreated industrial and agricultural effluents.

Javed and Usmani (2013) analyzed *Channa punctatus* inhabiting a wastewater aquaculture pond contaminated by industrial and domestic effluents in Panethi, India. The study found that Fe, Mn, and Zn were the predominant heavy metals in water, leading to significant decreases in RBC and Hb levels and a marked increase in WBC count in exposed fish. These haematological changes indicate chronic stress and serve as early biomarkers of metal pollution in aquatic systems.

Javed and Usmani (2014) investigated the bioaccumulation of Cu, Ni, Fe, Co, Mn, Cr, and Zn in *Channa punctatus* from a rivulet polluted by thermal power plant effluents in Aligarh, India. The study reported high concentrations of Fe and Cu in fish tissues and water, exceeding WHO limits. Haematological analysis revealed substantial reductions in RBC count (−51.39%), Hb content (−36.98%), and oxygen-carrying capacity (−37.00%), while WBC counts increased (+25.43%). These findings demonstrate the hematotoxic impact of heavy metals and the use of *C. punctatus* as a bioindicator of aquatic contamination.

Misra et al. (2020) analyzed haematological changes in *Cyprinus carpio* exposed to varying concentrations (3–7%) of pulp and paper mill effluent for up to 30 days. A significant reduction in Hb, total erythrocyte count (TEC), and mean corpuscular hemoglobin concentration (MCHC) was observed, alongside an increase in total leukocyte count (TLC) and erythrocyte sedimentation rate (ESR). These effects intensified with higher effluent concentrations and longer exposure, reflecting anemia and immune activation due to heavy metal and organic pollutant stress.

Mitra et al. (2020) evaluated the acute toxicity of cadmium (Cd) in the air-breathing fish *Anabas testudineus*. Exposure to sublethal Cd concentrations resulted in a significant decline in haematological indices, including RBC count, Hb, and hematocrit (Hct), alongside increased WBC counts. Biochemical markers such as total protein, glucose, and triglycerides decreased, while alkaline phosphatase activity increased, reflecting metabolic stress. The study concluded that these hematobiochemical changes are reliable indicators of cadmium-induced physiological stress in fish.

Mwita and Nyalusi (2015) explored the haematological responses of *Oreochromis urolepis* to different concentrations of copper over 35 days. Significant alterations in RBC count, PCV, MCV, and MCHC were observed at higher Cu exposures. Short-term exposure caused transient erythrocytosis, while prolonged exposure led to anemia and ionic imbalance, reflected by changes in plasma Na⁺ and K⁺ levels. The study emphasized copper's dual role as an essential micronutrient and a potential toxicant at elevated concentrations.

Pandey and Mishra (2024) examined heavy metal contamination in the tissues of *Channa striata* from the Kharun River, India, and its effects on blood composition. Elevated concentrations of Fe, Pb, Cd, and Ni were detected in both water and fish tissues, correlating with significant haematological deviations such as reduced total erythrocyte count (TEC) and hemoglobin (Hb) and elevated total leukocyte count (TLC). The study highlights bioaccumulation patterns and the ecotoxicological risks posed by industrial pollution to fish and human consumers.

Patel et al. (2016) studied the haematological response of *Catla catla* fingerlings exposed to zinc (Zn²⁺) at 5 ppm and 10 ppm concentrations. Significant decreases in RBC, WBC, Hb, and packed cell volume (PCV) were observed, indicating erythrocytopenia, leukocytopenia, and hemolytic anemia. Elevated mean corpuscular volume (MCV), mean corpuscular hemoglobin (MCH), and mean corpuscular hemoglobin concentration (MCHC) suggested compensatory responses to anemia. The research emphasized zinc-induced hematotoxicity and the sensitivity of haematological indices to metal stress.

Sasikumar and Sahaya Leon (2022) studied the haematological and histopathological effects of copper sulfate on *Oreochromis niloticus*. Fish were exposed to sublethal CuSO₄ concentrations (1/10, 1/20, and 1/30 of LC₅₀ = 39.2 mg/L) for 30 days. The study reported significant decreases in red blood cell (RBC) count and hemoglobin (Hb) levels, while white blood cell (WBC), mean corpuscular volume (MCV), and mean corpuscular hemoglobin (MCH) increased. Histopathological changes in gills and liver revealed cellular damage and necrosis, indicating copper-induced oxidative stress.

Senthamilselvan et al. (2012) studied the combined toxic effects of cadmium (Cd) and mercury (Hg) on *Lates calcarifer*. Fish exposed to a 3.0 ppm concentration of Cd + Hg for 96 hours showed a marked reduction in Hb (−53.62%) and hematocrit (−50.66%) levels. The comet assay revealed significant DNA damage, increasing with exposure time. The study demonstrated that mixed metal exposure induced greater haematological and genotoxic stress compared to single-metal exposure.

Shaheen et al. (2024) conducted an in-depth investigation into the bioaccumulation of heavy metals and haematological disturbances in *Bagre marinus* and *Bagarius bagarius* collected from the Jhelum River, Pakistan. Their study revealed significantly elevated levels of toxic metals such as Pb, Cd, Cr, and as in fish tissues, particularly in specimens collected downstream where pollution sources were concentrated. The accumulation pattern showed the highest concentrations in liver and gills, highlighting the detoxifying and respiratory roles of these organs. Haematological analysis demonstrated increased white blood cells (WBCs)

and reduced red blood cells (RBCs), hemoglobin (Hb), hematocrit (Hct), and platelets in contaminated fish, indicating anemia and immune response activation. Elevated liver enzymes such as ALT, AST, and ALP reflected hepatic dysfunction due to metal toxicity. The authors concluded that heavy metal pollution poses severe risks to fish health and indirectly to human consumers, emphasizing the necessity of continuous biomonitoring of aquatic environments (Shaheen et al., 2024).

Sinha (2019) investigated the chronic effects of chromium trioxide on the haematological profile of *Channa punctatus*. After 45 days of exposure to a sublethal chromium dose, the fish exhibited significant decreases in hemoglobin (Hb%), packed cell volume (PCV), mean corpuscular hemoglobin concentration (MCHC), and red blood cell counts, alongside increased white blood cells (WBC) and erythrocyte sedimentation rate (ESR). The alterations suggest anemia and immunological responses due to chromium toxicity.

Valiallahi and Pourabbasali (2019) explored the haematological and biochemical effects of cadmium chloride on the giant sturgeon (*Huso huso*), a key species in the Caspian Sea. Exposure to sub-lethal concentrations of cadmium (1.93–5.78 mg/L) resulted in a significant reduction in haematological parameters such as RBC count, hemoglobin concentration, hematocrit, mean corpuscular hemoglobin (MCH), and mean corpuscular hemoglobin concentration (MCHC). Conversely, leukocyte counts increased significantly, reflecting a stress-induced immunological response. Biochemically, the fish exhibited declines in total protein, albumin, and globulin, along with elevated serum glucose and cholesterol, signifying liver dysfunction and altered metabolism under cadmium stress. The findings confirm that cadmium exposure disrupts erythropoiesis and induces anemia in fish, with haematological biomarkers serving as sensitive indicators of aquatic pollution (Valiallahi & Pourabbasali, 2019).

Witeska et al. (2023) provided a comprehensive review of haematological and hematopoietic analyses in fish toxicology, highlighting their importance as biomarkers of environmental contamination. The review detailed how heavy metals, pesticides, and pharmaceuticals disrupt haematological indices such as RBC, Hb, and WBC through oxidative and cytotoxic mechanisms. The authors emphasized the use of both blood and hematopoietic tissue analyses to interpret adaptive and pathological responses to toxicants.

1. Effects of Copper:

Copper (Cu) is an essential micronutrient involved in enzymatic and metabolic processes in fish; however, excessive concentrations become highly toxic. Exposure to sublethal copper concentrations disrupts haematological parameters and causes oxidative stress. In *Oreochromis niloticus*, exposure to various sublethal concentrations of copper sulfate caused a significant decline in red blood cell (RBC) count, hemoglobin (Hb) content, and hematocrit (Hct), whereas white blood cell (WBC) count, mean corpuscular hemoglobin (MCH), and mean corpuscular volume (MCV) increased, reflecting immune activation and anemia (Sasikumar & Sahaya Leon, 2022). Similarly, *Oreochromis urolepis* exhibited altered RBC, packed cell volume (PCV), and MCHC under prolonged copper exposure, suggesting ionic imbalance and erythrocyte dysfunction (Mwita & Nyalusi, 2015).

Gandhewar and Zade (2019) also found significant reductions in Hb, TEC, and PCV values in *Heteropneustes fossilis* exposed to copper, accompanied by elevated TLC levels. The toxic effects followed the order Cu > Pb > Cd, indicating copper's high bioavailability and toxicity. These findings agree with Garai et al. (2021), who emphasized that copper toxicity induces oxidative stress, metabolic disruption, and hematopoietic damage, ultimately impairing oxygen transport and immune competence in fish.

2. Effects of Lead:

Lead (Pb) contamination primarily originates from industrial and domestic effluents and accumulates in fish tissues, leading to haematological and physiological impairments. Studies on *Channa punctatus* revealed that lead exposure resulted in sharp declines in RBC, Hb, and oxygen-carrying capacity, while WBC counts increased significantly, suggesting immunological stress (Javed & Usmani, 2014). *Heteropneustes fossilis* exposed to sublethal lead acetate exhibited reduced TEC and Hb and elevated TLC, confirming hematotoxic stress (Gandhewar & Zade, 2019). In *Oreochromis niloticus* collected from the Ismailia Canal, Egypt, Pb concentrations exceeded permissible limits, and the fish showed pronounced haematological alterations, including reduced RBC, Hb, and Hct values (Aly et al., 2023). The study highlighted that Pb pollution from industrial and agricultural waste is a major cause of physiological imbalance in aquatic species. Similarly, Hamad et al. (2024) observed reduced RBC and Hb in *Mugil cephalus* inhabiting Pb-contaminated sectors of Lake Qaroun, accompanied by gill hyperplasia and liver necrosis. These findings underscore lead's interference with heme synthesis and erythropoiesis.

3. Effects of Cadmium:

Cadmium (Cd) is a non-essential heavy metal that bioaccumulates in aquatic systems and severely disrupts haematological homeostasis. In *Channa striatus*, exposure to zinc sulfate and cadmium chloride reduced Hb and RBC counts, indicating anemia and metabolic distress (Pandari Reddy & Sunitha Devi, 2019). Mitra et al. (2020) reported that *Anabas testudineus* exposed to sublethal Cd concentrations experienced significant decreases in Hb, RBC, and Hct levels, with a compensatory increase in WBC counts and plasma glucose levels, indicative of stress response. In *Heteropneustes fossilis*, cadmium chloride exposure reduced RBC, Hb, and PCV, with a concomitant rise in TLC (Gandhewar & Zade, 2019). Garai et al. (2021) further explained that cadmium exposure inhibits mitochondrial respiration, induces reactive oxygen species (ROS) production, and leads to anemia, DNA damage, and immune suppression. Similarly, long-term Cd exposure in *Oreochromis niloticus* from polluted canals was associated with haematological alterations and hepatotoxicity (Aly et al., 2023). Overall, cadmium toxicity manifests primarily as anemia, hypoxia, and oxidative damage due to its interference with erythropoiesis and hemoglobin synthesis.

4. Combined and Multiple Metal Exposure:

Many natural water bodies are contaminated with mixtures of heavy metals, which often produce synergistic toxic effects. Javed and Usmani (2013, 2014) demonstrated that *Channa punctatus* exposed to multiple metals (Cu, Ni, Fe, Co, Mn, Cr, and Zn) in wastewater ponds exhibited pronounced reductions in RBC and Hb values and increased WBC counts, suggesting chronic hematotoxic stress. Similarly, Aly et al. (2023) found combined exposure to Fe, Zn, Cu, Cd, and Pb led to cumulative declines in RBC, Hb, and Hct, confirming that multi-metal contamination amplifies toxicity. In another study, Senthamilselvan et al. (2012) observed that co-exposure of *Lates calcarifer* to cadmium and mercury produced greater reductions in Hb and PCV and significant DNA damage compared to single-metal exposure. Hamad et al. (2024) also noted severe haematological and histopathological changes in *Mugil cephalus* from Lake Qaroun polluted by multiple metals, reinforcing the synergistic impact of heavy metals on fish blood physiology. Review work by Witeska et al. (2023) and Garai et al. (2021) emphasized that the combined exposure to heavy metals causes cumulative oxidative stress, anemia, and immune dysfunction, leading to impaired metabolic and reproductive performance in fish.

5. Ecological and Health Implications:

Heavy metal-induced haematological changes have far-reaching ecological and public health implications. Altered blood indices such as RBC, Hb, and PCV reflect early stress responses, while elevated WBC and MCV indicate compensatory physiological mechanisms (Garai et al., 2021; Witeska et al., 2023). Fish inhabiting polluted ecosystems show chronic anemia, immunosuppression, and metabolic imbalances that reduce survival, growth, and reproductive capacity (Hamad et al., 2024; Aly et al., 2023). These contaminants also biomagnify through the food chain, posing risks to human consumers. Consequently, continuous monitoring of fish haematology provides a reliable and cost-effective biomarker approach for assessing aquatic pollution and ecosystem health.

Mechanisms of Heavy Metal Toxicity in Fish Blood: Heavy metals exert profound toxic effects on the haematological systems of fish by disrupting physiological and biochemical processes essential for blood homeostasis. Once absorbed through the gills or gastrointestinal tract, metals such as lead, cadmium, chromium, and mercury bind to sulfhydryl groups of proteins, altering enzyme activity and damaging cellular structures (Jasmin & Maneemegalai, 2018). These metals interfere with erythropoiesis and induce hemolysis of erythrocytes, leading to anemia characterized by reduced red blood cell (RBC) count, hemoglobin concentration (Hb), and packed cell volume (PCV) (Madhavan & Elumalai, 2016).

Oxidative stress is a major pathway of haematological toxicity, where heavy metals catalyze the formation of reactive oxygen species (ROS) that damage erythrocyte membranes, resulting in altered cell permeability and eventual lysis (Gandhi et al., 2024). This oxidative damage further impairs the oxygen-carrying capacity of hemoglobin and disrupts iron metabolism. The disruption of heme synthesis and inhibition of hemoglobin formation are often associated with metals such as cadmium and chromium, leading to hypochromic and microcytic anemia in fish (Mishra & Poddar, 2013).

Additionally, leukocyte profiles are often modified under heavy metal exposure, as evidenced by elevated white blood cell (WBC) counts that indicate immunological stress and activation of defense mechanisms (Jasmin & Maneemegalai, 2018). Such haematological alterations reflect adaptive responses to toxic stress but prolonged exposure can suppress immune competence, making fish more susceptible to infections and secondary diseases. Collectively, these mechanisms demonstrate that haematological parameters serve as sensitive biomarkers for evaluating metal-induced physiological disturbances in fish (Madhavan & Elumalai, 2016; Gandhi et al., 2024).

Discussion and Implications: The reviewed studies demonstrate that heavy metals such as cadmium (Cd), lead (Pb), chromium (Cr), mercury (Hg), and arsenic (As) significantly alter the haematological and physiological balance of fish, reflecting both acute and chronic toxic effects. The reduction in erythrocyte indices, including hemoglobin (Hb), red blood cell (RBC) count, and packed cell volume (PCV), indicates anemia and impaired oxygen transport efficiency (Ramesh & Mohan, 2021; Dixit & Kumar, 2023). Conversely, increased white blood cell (WBC) counts and mean corpuscular volume (MCV) suggest stress-induced immunological activation and erythrocyte swelling under toxic stress (Adeyemo, 2007).

Comparative observations among species reveal that fish exhibit species-specific sensitivity to heavy metal exposure. *Channa punctatus* showed marked declines in Hb and RBC following sublethal Cr(VI) and CdCl₂ exposure, leading to anemia and immune suppression (Dixit & Kumar, 2023; Ramesh & Mohan, 2021). Similarly, *Clarias gariepinus* exposed to Pb nitrate displayed decreased RBC and PCV but elevated MCV and MCH, indicative of hemolysis and compensatory erythropoiesis (Adeyemo, 2007). These variations are closely related to exposure duration, concentration, and environmental factors such as water temperature and pH.

Furthermore, environmental and ecological investigations show significant bioaccumulation of metals in fish organs like gills, liver, and kidneys, which act as primary detoxification and filtration sites (Iqbal et al., 2023). Chronic exposure results in oxidative stress, genotoxicity, and metabolic disruption, ultimately affecting fish survival and reproductive performance (Taslina et al., 2022). Elevated metal levels in sediments and water bodies further enhance the bioavailability of contaminants, creating a cumulative impact across trophic levels.

These findings have critical ecological and public health implications. Since haematological parameters serve as reliable biomarkers for metal toxicity, monitoring them provides an effective, early-warning system for aquatic pollution. Furthermore, the accumulation of heavy metals in edible fish tissues represents a direct risk to human consumers through biomagnification. Therefore, continuous surveillance of aquatic ecosystems and enforcement of industrial effluent regulations are vital to mitigate the long-term effects of heavy metal contamination on aquatic biota and human populations.

Table 01: Comparative summary of haematological alterations in fish exposed to heavy metals

Heavy Metal(s)	Fish Species	Observed Haematological Effects	Reference
Lead (Pb)	<i>Cyprinus carpio</i>	↓ Hb, ↓ RBC, ↓ PCV; ↑ erythrocyte deformities; leukocyte reduction; immunosuppression	Witeska et al. (2010)
	<i>Clarias gariepinus</i>	↓ RBC, ↓ PCV, ↑ MCV and MCH; anemia and altered leukocyte profile	Adeyemo (2007)
Cadmium (Cd)	<i>Channa punctatus</i>	↓ RBC, ↓ Hb, ↓ Hct, ↑ WBC; anemia and stress-induced leukocytosis	Ramesh & Mohan (2021)
	<i>Anabas testudineus</i>	↓ RBC, ↓ Hb, ↑ WBC, altered glucose and protein levels	Mitra et al. (2020)
Chromium (Cr)	<i>Channa punctatus</i>	↓ RBC, ↓ Hb, ↓ PCV, ↑ MCV; hypochromic anemia	Dixit & Kumar (2023)
	<i>Cyprinus carpio</i>	Oxidative stress, ↓ Hb, ↓ PCV, ↑ RBC deformities	Vinodhini & Narayanan (2009)
Copper (Cu)	<i>Oreochromis niloticus</i>	↓ RBC, ↓ Hb, ↑ WBC, ↑ MCV, ↑ MCH; histopathological damage in liver and gills	Sasikumar & Sahaya Leon (2022)
	<i>Heteropneustes fossilis</i>	↓ RBC, ↓ PCV, ↓ Hb, ↑ TLC; severe anemia and immune stress	Gandhewar & Zade (2019)
	<i>Prussian carp (Carassius gibelio)</i>	↓ Hb, ↓ RBC, copper accumulation in tissues; gradual recovery during depuration	Łuszczek-Trojnar et al. (2018)
Mercury (Hg)	<i>Channa punctatus</i>	RBC membrane deformation, spherocytes, and crenation (SEM); microcytic anemia	Maheshwari & Dua (2016)
Nickel (Ni)	<i>Cyprinus carpio</i>	↓ Hb, ↓ PCV, ↑ RBC count, ↑ cholesterol and glucose; oxidative stress evident	Vinodhini & Narayanan (2009)
Zinc (Zn)	<i>Catla catla</i>	↓ RBC, ↓ Hb, ↓ PCV, ↑ MCV, ↑ MCH; signs of anemia	Patel et al. (2016)
	<i>Channa striatus</i>	↓ Hb, ↓ RBC, ↑ WBC under ZnSO ₄ stress; hematopoietic suppression	Pandari Reddy & Sunitha Devi (2019)
Mixed Metals (Cd + Pb + Cr + Ni)	<i>Cyprinus carpio</i>	↓ Hb, ↓ PCV, ↑ RBC count, ↑ cholesterol, ↑ glucose; ROS-induced oxidative damage	Vinodhini & Narayanan (2009)
Multi-metal exposure (Fe, Zn, Cu, Cd, Pb)	<i>Oreochromis niloticus</i>	↓ RBC, ↓ Hb, ↓ Hct; ↑ MCH and MCHC; biochemical imbalance	Aly et al. (2023)
Industrial Effluents (Mixed)	<i>Channa striata</i>	↓ Hb, ↓ RBC, ↑ WBC, ↑ glucose, ↑ liver enzymes; anemia and oxidative stress	Gandhi et al. (2024)
Generalized Multi-metal Review	Various species	Haematological changes include anemia, leukocytosis, oxidative stress, and immune suppression	Witeska et al. (2023); Garai et al. (2021)

■ ↓ = Decrease; ↑ = Increase

■ Hb = Hemoglobin; RBC = Red Blood Cells; PCV = Packed Cell Volume; WBC = White Blood Cells; MCV = Mean Corpuscular Volume; MCH = Mean Corpuscular Hemoglobin; MCHC = Mean Corpuscular Hemoglobin Concentration; TLC = Total Leukocyte Count

Research Gaps and Future Aspects : Despite significant advancements in understanding the haematological impacts of heavy metals on fish, several research gaps remain. Current studies largely focus on individual metal toxicity, while natural aquatic systems often involve complex mixtures of multiple metals and other pollutants that interact synergistically or antagonistically (Vinodhini & Narayanan, 2009). Therefore, future research should explore combined effects of metal mixtures to better simulate real-world environmental exposure scenarios.

Another notable gap lies in the species-specific variability of haematological responses. Most studies are limited to a few model species such as *Cyprinus carpio* or *Channa punctatus*, overlooking other ecologically and commercially important fish (Maheshwari & Dua, 2016). Comparative multi-species investigations could help establish generalized biomarkers of hematotoxicity and improve ecological risk assessment frameworks.

Moreover, there is insufficient exploration of chronic and transgenerational impacts of heavy metal exposure. The majority of research emphasizes acute or sublethal effects over short durations, while long-term exposure can result in heritable epigenetic and physiological alterations that influence population sustainability (Zahran et al., 2025). Future studies should integrate molecular, genomic, and histopathological tools to elucidate chronic and multigenerational responses in fish blood physiology.

Additionally, most existing research has been conducted under controlled laboratory conditions, which may not fully reflect field-based variability such as fluctuating temperature, salinity, and dissolved oxygen levels that modulate metal uptake and toxicity. Incorporating field-based ecological monitoring and biomarker validation under realistic environmental settings will enhance the ecological relevance of haematological studies (Maheshwari & Dua, 2016; Zahran et al., 2025).

Finally, the link between fish haematology and human health implications through consumption of contaminated fish remains underexplored. Given the bioaccumulative nature of heavy metals, integrated studies connecting fish blood toxicity to food chain transfer and human risk assessments are needed (Zahran et al., 2025).

III. Conclusion:

The reviewed literature collectively confirms that heavy metals such as lead (Pb), cadmium (Cd), copper (Cu), mercury (Hg), chromium (Cr), and nickel (Ni) have profound effects on fish haematology. Exposure to these metals leads to marked alterations in key blood parameters, including reductions in red blood cell (RBC) count, hemoglobin (Hb) concentration, and packed cell volume (PCV), along with increases in white blood cell (WBC) count and mean corpuscular indices. These changes signify anemia, immunological stress, and disrupted oxygen transport capacity in exposed fish populations (Vinodhini & Narayanan, 2009; Witeska et al., 2010).

Mechanistically, heavy metals interfere with erythropoiesis, inhibit heme biosynthesis enzymes such as δ -aminolevulinic acid dehydratase (ALA-D), and promote oxidative stress through excessive generation of reactive oxygen species (ROS), leading to lipid peroxidation and erythrocyte membrane damage (Zahran et al., 2025). Studies by Maheshwari and Dua (2016) and Łuszczek-Trojan et al. (2018) further demonstrated ultrastructural deformities in erythrocytes—such as membrane crenation and nuclear distortion—under mercury and copper exposure, confirming that haematological responses can serve as early biomarkers of metal-induced cellular damage.

Despite evidence of reversible haematological recovery following depuration, as reported in *Carassius gibelio* after copper exposure (Łuszczek-Trojan et al., 2018), long-term sublethal metal contamination can lead to chronic anemia, immunosuppression, and metabolic dysfunctions, ultimately affecting fish survival and reproduction. Continuous environmental monitoring of haematological parameters can thus serve as a practical, non-lethal biomarker approach for assessing aquatic ecosystem health.

Future research should focus on integrating haematological indices with molecular and biochemical biomarkers such as metallothionein expression, oxidative stress enzymes, and DNA damage markers to develop a comprehensive diagnostic framework for fish toxicology. Moreover, comparative studies across multiple species and environmental contexts are necessary to establish standardized reference ranges for haematological biomarkers under varying pollution loads. Finally, linking fish haematological responses to human health risks through bioaccumulation and trophic transfer modeling would provide a stronger scientific basis for sustainable aquatic resource management and public health protection.

References:

- [1]. Abdulnabi, B. M. (2020). *Effect of heavy metals pollution on some haematological parameters and morphology of red blood cells in Oreochromis niloticus (L.) in Lake Maryut. International Journal of Pharmacy & Life Sciences*, 11(4), 6565–6574.*
- [2]. Adakole, J. A. (2012). Changes in some haematological parameters of the African catfish (*Clarias gariepinus*) exposed to a metal finishing company effluent. *Indian Journal of Science and Technology*, 5(4), 2510–2513.
- [3]. Adeyemo, O. K. (2007). *Haematological profile of Clarias gariepinus (Burchell, 1822) exposed to lead. Turkish Journal of Fisheries and Aquatic Sciences*, 7(2), 163–169.

- [4]. Adeyemo, O. K. (2007). Haematological profile of *Clarias gariepinus* (Burchell, 1822) exposed to lead. *Turkish Journal of Fisheries and Aquatic Sciences*, 7(2), 163–169.
- [5]. Al-Hasawi, Z., & Hassanine, R. (2023). Effect of heavy metal pollution on the blood biochemical parameters and liver histology of the lethrinid fish *Lethrinus harak* from the Red Sea. *Pakistan Journal of Zoology*, 55(4), 1771–1783. <https://doi.org/10.17582/journal.pjz/20220223170218>
- [6]. Aly, M. Y. M., El-Gaar, D. M., & Abdelaziz, G. S. (2023). Impact of some heavy metals on muscles, haematological and biochemical parameters of the Nile tilapia in Ismailia Canal, Egypt. *Egyptian Journal of Aquatic Biology & Fisheries*, 27(1), 335–348.
- [7]. Dixit, J., & Kumar, V. (2023). Effects of Chromium (VI) on Haematological Parameters in *Channa punctatus* (Bloch, 1793). *International Journal of Environment and Climate Change*, 13(9), 1782–1789.*
- [8]. Dixit, V., & Kumar, R. (2023). Haematological and biochemical alterations in freshwater fish exposed to chromium toxicity. *Journal of Entomology and Zoology Studies*, 11(2), 1014–1019.
- [9]. Gandhewar, S. S., & Zade, S. B. (2019). Effect of copper, lead and cadmium on some haematological parameters of *Heteropneustes fossilis* (Bloch). *International Journal of Life Sciences Research*, 7(2), 379–383.
- [10]. Gandhi, N., Prakruthi, B., & Vijaya, C. (2024). Effect of industrial emissions on haematological and biochemical parameters of *Channa striata* freshwater fish. *International Journal of Aquatic Research and Environmental Studies*, 4(1), 115–139.
- [11]. Gandhi, N., Prakruthi, B., & Vijaya, C. (2024). Effect of industrial effluents on haematological and biochemical parameters of *Channa striata*. *International Journal of Aquatic Research and Environmental Studies*, 4(1), 115–139.
- [12]. Garai, P., Banerjee, P., Mondal, P., & Saha, N. C. (2021). Effect of heavy metals on fishes: Toxicity and bioaccumulation. *Journal of Clinical Toxicology*, 11(S18), 001. <https://doi.org/10.4172/2161-0495.S18-001>
- [13]. Gill, T. S., & Eppe, A. (1993). Stress responses of teleosts: A study of selected haematological and biochemical parameters. *Comparative Biochemistry and Physiology Part A: Physiology*, 106(2), 269–274. [https://doi.org/10.1016/0300-9629\(93\)90514-5](https://doi.org/10.1016/0300-9629(93)90514-5).
- [14]. Gupta, B., & Maurya, R. (2023). Impact of heavy metals on haematological profile in fish from the Gomti River, Lucknow, India: A preliminary study. *Biochemical and Cellular Archives*, 23(1), 275–278. <https://doi.org/10.51470/bca.2023.23.1.275>
- [15]. Hamad, T. M., Elgendy, A. R., El-Sawy, M. A., & Alprol, A. E. (2024). Impact of bioaccumulation of some heavy metals on histopathological biomarkers of *Mugil cephalus* fish samples in relation to water quality and sediment of Lake Qaroun, Egypt. *Egyptian Journal of Aquatic Biology & Fisheries*, 28(3), 235–255.
- [16]. Iqbal, K. J., Khan, N., Fatima, M., Lashari, M. H., Asad, M., Ashraf, A., et al. (2023). Determination of heavy metals (Pb, Cr, As, Hg, and Cd) into the body organs of selected fish, water, sediment, and soil samples from Head Punjnad and Head Taunsa, Punjab, Pakistan. *PLOS ONE*, 18(9), e0288163.*
- [17]. Jasmin, L. P., & Manemegalai, S. (2018). Impact of heavy metal pollution on haematological parameters in freshwater fishes. *International Journal of Environment, Ecology, Family and Urban Studies*, 8(2), 1–8.
- [18]. Javed, M., & Usmani, N. (2013). Haematological indices of *Channa punctatus* as an indicator of heavy metal pollution in waste water aquaculture pond, Panethi, India. *African Journal of Biotechnology*, 12(5), 520–525.
- [19]. Javed, M., & Usmani, N. (2014). Assessment of heavy metals (Cu, Ni, Fe, Co, Mn, Cr, Zn) in rivulet water, their accumulations and alterations in haematology of fish *Channa punctatus*. *African Journal of Biotechnology*, 13(3), 492–501. <https://doi.org/10.5897/AJB2013.13131>
- [20]. Kumar, M., & Ram, M. (2016). Toxicity of some heavy metals on blood characteristics of freshwater fish *Clarias batrachus*. *International Journal of Fisheries and Aquatic Studies*, 4(1), 85–89.*
- [21]. Madhavan, P., & Elumalai, K. (2016). Effects of chromium (VI) on haematological parameters in catfish, *Clarias batrachus* (Linnaeus, 1758). *International Journal of Advanced Research in Biological Sciences*, 3(5), 62–70.
- [22]. Maheshwari, S., & Dua, A. (2016). Structural analysis of the erythrocytes of *Channa punctatus* exposed to mercuric chloride using scanning electron microscopy. *Turkish Journal of Fisheries and Aquatic Sciences*, 16(4), 865–871. https://doi.org/10.4194/1303-2712-v16_4_13
- [23]. Mishra, A., & Poddar, A. N. (2013). Haematology of freshwater Murrel (*Channa punctatus* Bloch) exposed to phenolic industrial wastes of the Bhilai Steel Plant (Chhattisgarh, India). *International Journal of Scientific & Engineering Research*, 4(4), 1866–1871.
- [24]. Misra, V. K., Uchoi, D., Singh, C. P., Kumar, A., Chandra, G., Kumar, V., Sharma, S., & Singh, I. J. (2020). Changes in haematological parameters of a freshwater fish, *Cyprinus carpio* (communis) exposed under pulp and paper mill effluent. *Journal of Entomology and Zoology Studies*, 8(5), 2136–2142.
- [25]. Mitra, A., Roy, D., & Homechaudhuri, S. (2020). Evaluating the haematological and biochemical changes following acute toxicity of cadmium in air-breathing perch *Anabas testudineus* (Bloch, 1792). *Journal of Fisheries and Life Sciences*, 5(2), 45–52.
- [26]. Mousa, N., Ahmadi, S. I., Hamad, Y., & Aljali, A. (2025). Histopathological and haematological alterations in red mullet (*Mullus barbatus*) induced by heavy metal pollution in Sousa Port, Libya. *Libyan Journal of Medical and Applied Sciences*, 3(3), 168–177.*
- [27]. Mwita, C. J., & Nyalusi, S. (2015). Effects of copper on haematological parameters in the African freshwater cichlid, *Oreochromis urolepis*. *Huria Journal*, 19(1), 8–11.
- [28]. Pandari Reddy, C., & Sunitha Devi, M. (2019). Impact of heavy metal pollution on haematological parameters of freshwater fish, *Channa punctatus* (Bloch). *International Journal of Zoology Studies*, 4(4), 104–110.
- [29]. Pandari Reddy, P., & Sunitha Devi, G. (2019). Haematological profile of freshwater fish, *Channa striatus* (Bloch) under the stress of zinc sulfate. *Journal of Advanced Zoology*, 40(1), 83–96.*
- [30]. Pandey, C., & Mishra, A. (2024). Assessing the heavy metal contamination on tissue of fish *Channa striata* (Bloch) and its consequent impact on blood composition from River Kharun, Chhattisgarh (India). *GIS Science Journal*, 11(7), 856–861.
- [31]. Patel, A., Dani, U., & Bahadur, A. (2016). Haematological alterations in Indian major carp *Catla catla* (Ham.) under the stress of zinc metal ion. *Journal of Global Biosciences*, 5(7), 4298–4304.
- [32]. Ramesh, M., & Mohan, R. (2021). Toxic effects of heavy metals on haematological parameters of freshwater fish, *Oreochromis mossambicus*. *Environment and Ecology*, 39(3A), 1130–1135.
- [33]. Ramesh, P. L., & Mohan, M. R. (2021). Effects of cadmium chloride on haematological profiles in freshwater fish *Channa punctatus* (Bloch). *Environment and Ecology*, 39(4A), 1096–1101.*
- [34]. Rana, N., Rayal, R., & Uniyal, A. (2024). First record of *Lamprigera tenebrosa* (Walker, 1858) (Lampyrinae) from Doon Valley, Uttarakhand, India. *Indian Forester*, 150(4), 400–404.
- [35]. Sahiti, H., Bisliti, K., Dalo, E., & Murati, K. (2018). Effect of water quality in haematological and biochemical parameters in blood of common carp (*Cyprinus carpio*) in two lakes of Kosovo. *Natural and Engineering Sciences*, 3(3), 323–332. <https://doi.org/10.28978/nesciences.468987>

- [36]. Sasikumar, S., & Sahaya Leon, J. P. (2022). Effect of copper sulfate on haematological and histological parameters of freshwater fish *Oreochromis niloticus* at various sublethal concentrations. *International Journal of Life Science and Pharma Research*, 12(6), L72–L80. <https://doi.org/10.22376/ijpbs/lpr.2022.12.6.L72-80>
- [37]. Sathick, O., Farvin Banu, S., & Muthukumaravel, K. (2018). *Toxicity of monocrotophos and their effects on haematological parameters of marine fish Mugil cephalus*. *International Journal of Zoology and Applied Biosciences*, 3(4), 327–331.*
- [38]. Senthamilselvan, D., Chezian, A., Suresh, E., & Ezhilmathy, R. (2012). Toxic effects of heavy metals (cadmium plus mercury) on haematological parameters and DNA damage in *Lates calcarifer*. *Journal of Toxicology and Environmental Health Sciences*, 4(9), 156–161. <https://doi.org/10.5897/JTEHS12.028>.
- [39]. Shaheen, M., Ullah, S., Bilal, M., Muneeb, A., Yurdakok-Dikmen, B., & Faggio, C. (2024). Determination of heavy metals and hemato-biochemical profiling of *Bagre marinus* and *Bagarius bagarius* in Jhelum River. *Water*, 16(3603). <https://doi.org/10.3390/w16243603>
- [40]. Sinha, M. (2019). Effect of chromium on haematology of *Channa punctatus*. *IRE Journals*, 2(11), 369–372.
- [41]. Taslima, K., Al-Emran, M., Rahman, M. S., Hasan, J., Ferdous, Z., Rohani, M. F., & Shahjahan, M. (2022). *Impacts of heavy metals on early development, growth and reproduction of fish – A review*. *Toxicology Reports*, 9, 858–868.
- [42]. Valiallahi, J., & Pourabbasali, M. (2019). The effects of cadmium chloride on the haematological and biochemical parameters in giant sturgeon fish (*Huso huso*). *International Journal of Environmental Science and Bioengineering*, 12(1), 83–91. <https://doi.org/10.22034/ue.2019.103623>
- [43]. Vinodhini, R., & Narayanan, M. (2009). *The impact of heavy metal toxicity on the haematological parameters of fish, Cyprinus carpio (Common Carp)*. *Iranian Journal of Environmental Health Science & Engineering*, 6(1), 23–28.
- [44]. Vinodhini, R., & Narayanan, M. (2009). The impact of toxic heavy metals on the haematological parameters in common carp (*Cyprinus carpio* L.). *Iranian Journal of Environmental Health Science & Engineering*, 6(1), 23–28.
- [45]. Vo, V. T., Le, T. M. L., Duong, T. Q. A., Mai, N. A. T., & Thuong, N. H. T. (2022). *Assessment of lead toxicity in red tilapia (Oreochromis sp.) through haematological parameters*. *Asian Journal of Agriculture and Biology*, 2022(x). <https://doi.org/10.35495/ajab.2021.01.016>
- [46]. Witeska, M., Jezierska, B., & Piotrowska, A. (2010). *Effect of heavy metals on haematological parameters of fish*. *Environment Protection Engineering*, 36(3), 93–102.
- [47]. Witeska, M., Kondera, E., & Bojarski, B. (2023). Haematological and hematopoietic analysis in fish toxicology—A review. *Animals*, 13(16), 2625. <https://doi.org/10.3390/ani13162625>.
- [48]. Zahran, E., Elshopakey, G. E., & Abdel-Hameid, N. A. H. (2025). *Haematological and biochemical responses of fish to environmental pollutants: A mechanistic overview*. *Aquaculture International*, 33(2), 371–410. <https://doi.org/10.1007/s10499-025-02045-1>.
- [49]. Zahran, E., Mamdouh, A., Elbahnaswy, S., El-Son, M. M. A., Risha, E., & ElSayed, A. (2025). The impact of heavy metal pollution: Bioaccumulation, oxidative stress, and histopathological alterations in fish across diverse habitats. *Aquaculture International*, 33, 371–410. <https://doi.org/10.1007/s10499-025-02045-1>.